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Road and Structure Protection Through Weight Control

Bridge Testing

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1/ INTRODUCTION

It is common knowledge that many of the existing thousands of North American bridges which, by conventional theoretical standards, are not capable of carrying the heavy vehicles of modern traffic, are indeed carrying these vehicles as a matter of routine without showing signs of distress. The obvious conclusion drawn from such knowledge is that there are large differences between the actual load-carrying capacities of bridges and those predicted by the conventional theory. Bridges, however, have finite capacities and the difference between their actual and assumed capacities, howsoever large, cannot be indiscriminately relied upon. To get the maximum use out of a bridge, its assessed load- carrying capacity should be safely close to its actual capacity. Bridge testing provides a much needed means of correctly assessing the strength of a bridge. It is both a science and an art, requiring personnel with specialized knowledge. When carefully planned and executed, and complemented by confirmatory analysis, it is the surest way of determining the load-carrying capacity of a bridge.

The structural research office of Ontario's Ministry of Transportation and Communications has been regularly testing bridges for the past fifteen or so years. It is perhaps the only organization in the world where proof testing of bridges is used on a regular basis to evaluate the load-carrying capacity of bridges.

The term "proof testing" deserves some explanation. In some contexts, it means the subjecting of a structure to service loads. In the context of bridges, a proof test may imply the placing of normal heavy vehicles carrying maximum legal loads on the bridge. Proof testing relevant to the Ontario bridge testing program, however, is used in a different sense. In this case the applied vehicle loads, besides accounting for maximum permissible vehicle weights, also take account of the load factor and dynamic load allowance. It is recalled that a load factor accounts for possible violations of permissible vehicle weights and the likely increase of permissible vehicle loads during the lifetime of a bridge. The dynamic load allowance caters for the increase in load effects caused by a vehicle crossing the bridge at a much greater speed than the crawling speed of the test vehicle.

Typically, in a proof test the test vehicle carries about twice the load that a normal vehicle is legally permitted to carry.

More than 150 bridges have been tested in Ontario during recent years. These tests have conclusively shown that most bridges possess a far greater reserve of strength than they are given credit for by analytical evaluations. The same conclusion (i.e., that of the presence of large reserve strengths in bridges) can also be drawn from the fact that most of the older bridges now carry much heavier loads than they were designed for, without showing any apparent signs of distress.

2/ TYPES OF TEST

For many centuries, it has been the practice to test new bridges to ascertain if they are sound. This process has usually consisted of loading the bridge with uniformly distributed dead load, being the equivalent of service loads. If the bridge did not collapse or show excessive deflections under these loads, it was considered to be sound. In recent times, bridges testing has become more sophisticated and today is also used for the evaluation of realistic load-carrying capacities of existing bridges.

Depending upon the primary reason for carrying out a load test, bridge testing can be classified into five categories as follows.

2.1/ Behaviour Tests

These tests are carried out to verify the results of a method or methods of analysis which, if validated, could be used in the load-carrying capacity evaluation of similar bridges. The applied loads during such a test are kept well below the safe loads of the structure. The test, therefore, provides information only on the load distribution in the structure and furnishes little data on its strength.

2.2/ Proof Tests

These test are carried out to establish the safe load-carrying capacity of a specific bridge. During these tests, the structures are subjected

to exceptionally high static loads. The loads are such that responses due to them are higher than those caused by the maximum allowable loads on the bridge, including the appropriate values of the load factors and dynamic load allowance (the impact factor). However, subjecting a bridge to a high enough load alone is not always a confirmation of its load-carrying capacity. Supporting analysis must be carried out to ensure that the observed bridge strength is not due to a temporary feature of the structure, such as for example, due to frozen bearings in a steel truss bridge.

2.3/ Ultimate-Load-Tests

These tests are carried out to determine the ultimate load-carrying capacity of bridges usually to confirm the ultimate strength assessment by some methods of strength analysis. After validation by an ultimate load test on an existing bridge, the methods can be used with some confidence on other similar structures.

2.4/ Stress History Tests

These tests are carried out to establish the distribution of stress ranges in fatigue-prone areas of bridges. The data, which are continuously obtained due to normal passage of vehicles on the bridge, are used to establish the fatigue life of the bridge.

2.5/ Diagnostic Tests

When the cause of the failure of a component on a bridge is not easily established by calculations, load tests on the bridge can be used to find the reason for the damage. Such tests usually involve the monitoring of a component similar to the one which has failed.

3/ EQUIPMENT REQUIRED

3.1/ Loading

Since the loads applied in a proof test are exceptionally high, it is not prudent for personnel to remain in the vicinity of the structure during

the testing operation. Therefore, it is advisable that all the loading and response monitoring equipment be capable of being handled remotely from the bridge.

A structure can be loaded by ballast, e.g., concrete blocks, which is placed on the structure by a large crane or by trucks with axle weights governed by ballast placed on them.

Of the many disadvantages of the ballast-blocks type of loading, the main one is that the load cannot be removed quickly from the bridge in the case of a distress warning. The lack of manoeuvreability of the ballast blocks also inhibits the testing of the structure for various load cases.

A loaded vehicle, representing heavy commercial vehicles, is an ideal means of applying loads to a bridge during the proof test. Ontario has two testing vehicles; each of these has five axles and is capable of being loaded to a gross weight of about 100 t. The vehicles are each equipped with remote-control driving devices and a crane. The latter is used to load the vehicle with 1 t concrete blocks.

3.2/ Response Monitoring Equipment

Two kinds of responses, namely deflections and strains, are usually measured during a bridge test. Because of the necessity of staying well away from the bridge during the test, these responses are best measured by electronic instruments such as electrical resistance strain gauges and displacement transducers. Readings from these instruments can be recorded by relatively inexpensive but rather slow hand-held meters. Alternatively, and indeed preferably, the responses can be recorded through a computer-based data acquisition system. The latter is used in Ontario.

The equipment required for monitoring the responses of a bridge during a load test can vary from a few dial gauges recorded manually to a great number of electrical resistance strain gauges, load cells, etc., recorded through a computer-based data acquisition system. The following is a

list of the various response-measuring devices and data-acquisition and recording systems used by the Structural Research Office of Ontario's Ministry of Transportation and Communications during many years of bridge testing.

- Mechanical Dial Gauges
- Mechanical Strain Gauges
- Electrical Resistance Strain Gauges
- Acoustic Strain Gauges
- Laser Gauges
- Deflectometers
- Displacement Transducers
- Levels
- Theodolites
- Thermocouples
- Separation Indicators
- Accelerometers

The list of the data-acquisition systems is as follows.

- Portable Strain Meter
- Switch and Balance Unit
- Computer-based Static Data-Acquisition System
- Computer-based Dynamic Data-Acquisition System
- Tape Recorders
- Strip-chart Recorders
- Mobile Lab

The total cost of equipment, including the relevant software, is about Cdn $660 000. It is noted that most of the equipment, such as the testing vehicles and the data-acquisition system, is not used exclusively for bridge testing.

4/ PERSONNEL REQUIRED

A large number of persons with different skills is required in the testing operation. Typically, for an average proof test in Ontario, the following personnel take part in the testing operation.

a) **Project engineer**, who is responsible for establishing the instrumentation requirements, pre-test and post-test analysis, and most importantly, for deciding upon the load levels that can be applied to the bridge without damaging it.

b) **Job captain**, who is responsible for making all arrangements for the test, including co-ordination between the various equipment operators, marking load positions on the bridge, ensuring that instruments are installed on the bridge according to the plans, and implementing the necessary safety precautions.

c) **Instrumentation technicians**, whose job it is to install the instruments, such as strain gauges, on the bridge and to operate the data- acquisition system.

d) **Truck drivers of the test vehicle**, who are experienced in driving the test vehicles either manually or by remote control and stopping at prescribed locations on the bridge.

e) **Surveyors**, who take measurements of the structure if drawings are not available.

In addition to the above, personnel are also required for traffic control, for guarding the instruments at night, and for providing access to the bridge for instrumentation.

5/ ONTARIO'S EXPERIENCE IN BRIDGE TESTING

As mentioned earlier, more than 150 bridges have been tested in Ontario over the past 15 or so years. Nearly one-third of the tests conducted were proof tests, which almost invariably concluded that the load- carrying capacities of the tested bridges were substantially higher than the capacities obtained by calculation. A dramatic, although not typical illustration of evaluation by testing is the, by now, well publicized photograph of a timber bridge with a posting sign of 5 tons, and carrying two test vehicles each carrying about 90 tonnes. It is not suggested that bridge testing will always confirm in such dramatically higher capacities.

It is, however, stressed that in most cases bridge testing will give a more realistic assessment of the load-carrying capacity of a bridge than can be obtained analytically.

The following table lists the number of bridges in Ontario which were considered structurally suspect but were declared safe after testing during the past nine years. The table also shows the approximate replacement cost for these bridges in 1984 Canadian dollars.

Table 1/ Bridge Test Results

Year	No. of Bridges Declared Safe After Testing	Approximate Replacement Cost in Million $
1975	3	5.31
1976	3	1.95
1977	2	3.60
1978	0	0.00
1979	1	0.23
1980	0	0.00
1981	2	4.65
1982	4	2.30

It is noted that in 1978 and 1980 no proof tests were conducted. Bridge testing is a somewhat expensive proposition. The average costs of a bridge test, including minor behaviour tests, is about $13,000. The cost of a major bridge test is much higher, being of the order of $50,000. It will, however, be noted that savings in replacement costs outweigh the testing cost by a large margin so that there is a very large net saving. The added benefit of a systematic testing program is the invaluable knowledge which is acquired of the behaviour of bridges and which can be used to great advantage in the design of new bridges.

6/ REASONS FOR UNACCOUNTED RESERVE STRENGTHS

There are many factors which contribute to the fairly large reserve strengths in bridges which cannot be accounted for analytically. Some of these factors are given below.

a) Force Analysis
Approximate methods of determining the distribution of loads often give conservative answers.

b) Strength Analysis
The load-carrying capacity of a component may be determined by an approximate and conservative method.

c) Errors in Basic Assumptions
Some of the basic assumptions which are used in the design process may not be valid.

d) Interaction of Various Components
It is usual to design a structure on a component-by-component basis. In fact, there is usually a significant interaction of the various components which can significantly enhance the load-carrying capacity of the structure.

e) Actual Material Strengths
Strengths used in design are usually based on percentile values, implying that in most cases actual strengths will be larger than the values used in design. Use of the same strength values as used in design is thus likely to lead to an underestimate of the bridge strength.

f) Evaluation Philosophy
It is common to evaluate a bridge by the same process as is used for designing a new bridge. This procedure accounts for the largest errors in establishing realistic load-carrying capacities of bridges. A good evaluation procedure should make use of the differences in uncertainties that exist between a yet-to-be-built bridge and an existing one.

6.1/ Dynamic Load Allowance

The value of the dynamic load allowance (DLA), or impact factor as it is often called, has a considerable influence on the maximum vehicle weights that can be safely put on a bridge. The value of DLA depends upon the interaction of the vehicle and the structure. Two vehicles having similar axle weights but different spring systems are likely to induce different values of DLA on a bridge. It is physically almost impossible to determine a representative value of DLA for a bridge for all vehicles that are likely to transverse the bridge. A representative value of DLA can be obtained by monitoring the response of a bridge over a representative period of time. The actual monitoring of DLA automatically takes account of such factors and can be confidently included in the calculations. For example, the nature of backfill in spandrel-filled arches may not be determined with certainty. The monitored response, obviously, does implicitly take account of the actual backfill conditions.

7/ WEIGHING IN MOTION

A slab-on-girder bridge can be turned into a weighing device by simply attaching strain gauges to the bottom girder flanges and installing a pressure switch on the pavement close to the bridge. Strains are continuously recorded on a tape recorder. The static load response of the bridge can be obtained by numerically filtering out the dynamic strains. Data from the above-mentioned instruments can be supplemented by taking a continuous video recording of the bridge from a strategic location.

This method of weighing vehicles, without the drivers' knowledge, has already been used in Ontario to conduct three extensive vehicle weight surveys. A slight variation of the Ontario system is also being used in the USA to collect vehicle weight data.

A vehicle of known axle weights is required to calibrate the instrumented bridge. The system works best with right simply supported bridges having steel girders. However, with specially constructed strain transducers, bridges with concrete girders can also be employed.

Individual axle weights and their spacing can also be measured, but only on relatively short span (say 20 m) bridges.

Using the above system, a vehicle of known weight was weighed 31 times. The measured weights were found to be within +9 and -5% of the actual weight. It is noted that such discrepancies are known to exist even in static weighing scales.

8/ CONCLUSIONS

The tests indicated that most bridges possess a far greater reserve of strength than can be predicted by conventional theory. The interaction of the various components of bridges, which are usually designed by isolating them from the rest of the structure, plays an important role in enhancing the load-carrying capacity of a structure.

The testing of bridges, in spite of being a specialized and risk-prone pursuit requiring the attention of personnel with experience and expertise in the field, has proven to be the surest way to establish the optimum safe load-carrying capacity of a bridge. The rather high costs involved in the testing operation are more than offset by savings which are affected by allowing the bridges to be used up to their maximum safe limit.

Ontario

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